CONCEPT

1) Copy SNS Linac design up to 1.2 GeV

(Reduced beam current and relaxed schedule allow some design optimizations)

2) Use TESLA Cryomodules 1.2 ® 8 GeV

3) H- Injection at 8 GeV in Main Injector

þ **"Super-Beams" in FNAL Main Injector:**

2 MW Beam power, small emittances, and minimum (1.5 sec) cycle time

þ **Electrons and Protons(H-) in Same Linac**

Many other possible missions for unused linac cycles:

8 GeV ν program, 8 GeV electrons ==> XFEL, etc.

BENEFITS

Benefits to n and Fixed-Target Program

solves proton economics problem: > 5E18 Protons/hr at 8 GeV
operate MI with small emittances, high currents, and low losses

Benefits to Linear Collider R&D

1.5% scale demonstration of TESLA economics
Evades the Linear Collider R & D funding cap
Simplifies the Linear Collider technology choice
Establishes stronger US position in LC technology

Benefits to Muon Collider/n-Factory R&D

Establishes cost basis for P-driver and muon acceleration

Benefits to VLHC:

small emittances, high Luminosity
~4x lower beam current reduces stored energy in beam
Stage 1: reduces instabilities, allows small beam pipes
Stage 2: injection at final synchrotron-damped emittances

8 GeV Linac Parameters

8 GeV Injector Linac

8 GeV LINAC

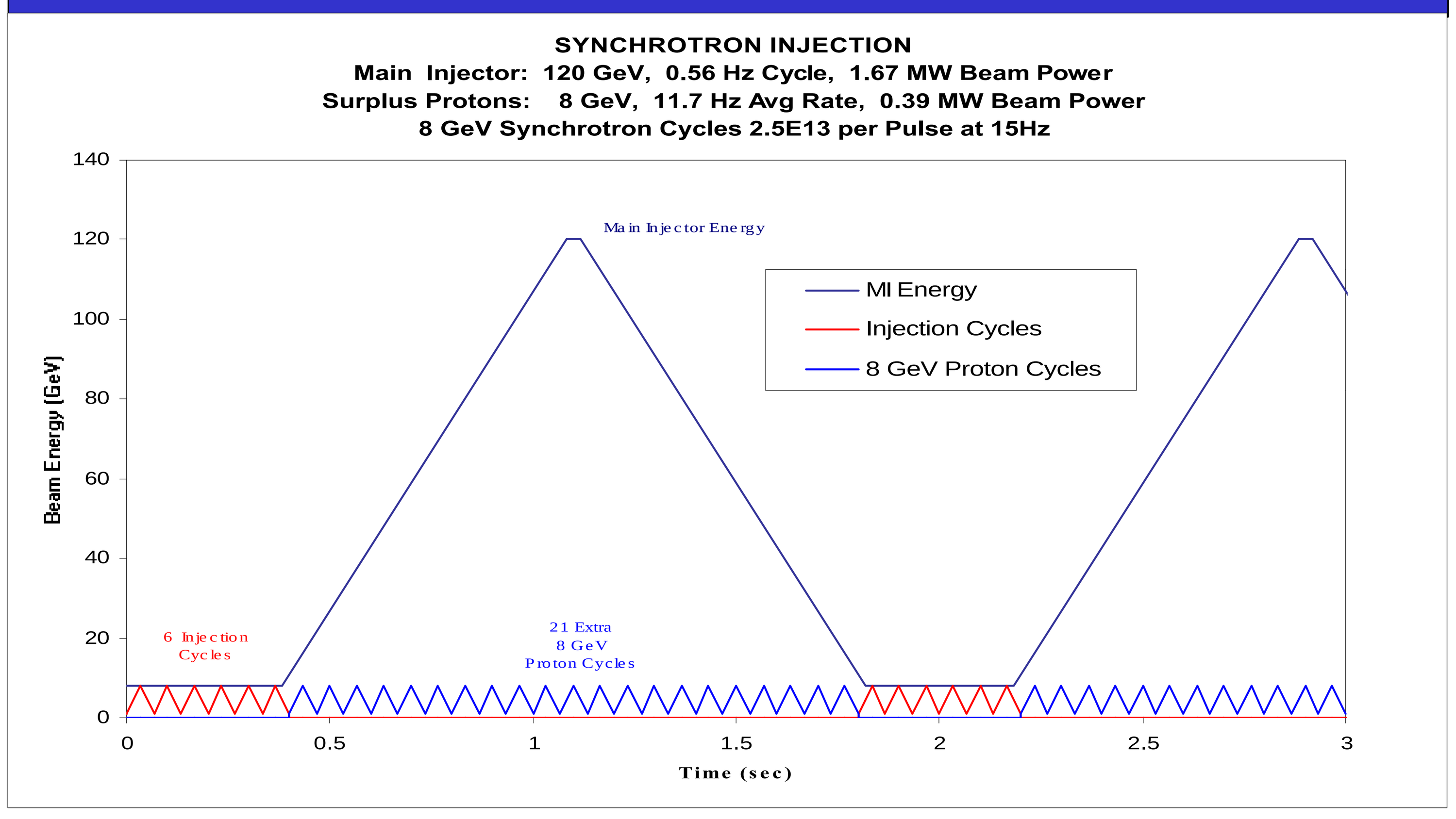
Energy	GeV	8	
Particle Type	H- Ions, Protons, or Electrons		
Rep. Rate	Hz	10	
Active Length	m	671	
Beam Current	mA	25	
Pulse Length	msec	1	
Beam Intensity	P / pulse	1.5E+14	(can be H-, P, or e-)
	P/hour	5.4E+18	
Linac Beam Power	MW avg.	2	
	MW peak	200	

MAIN INJECTOR WITH 8 GeV LINAC

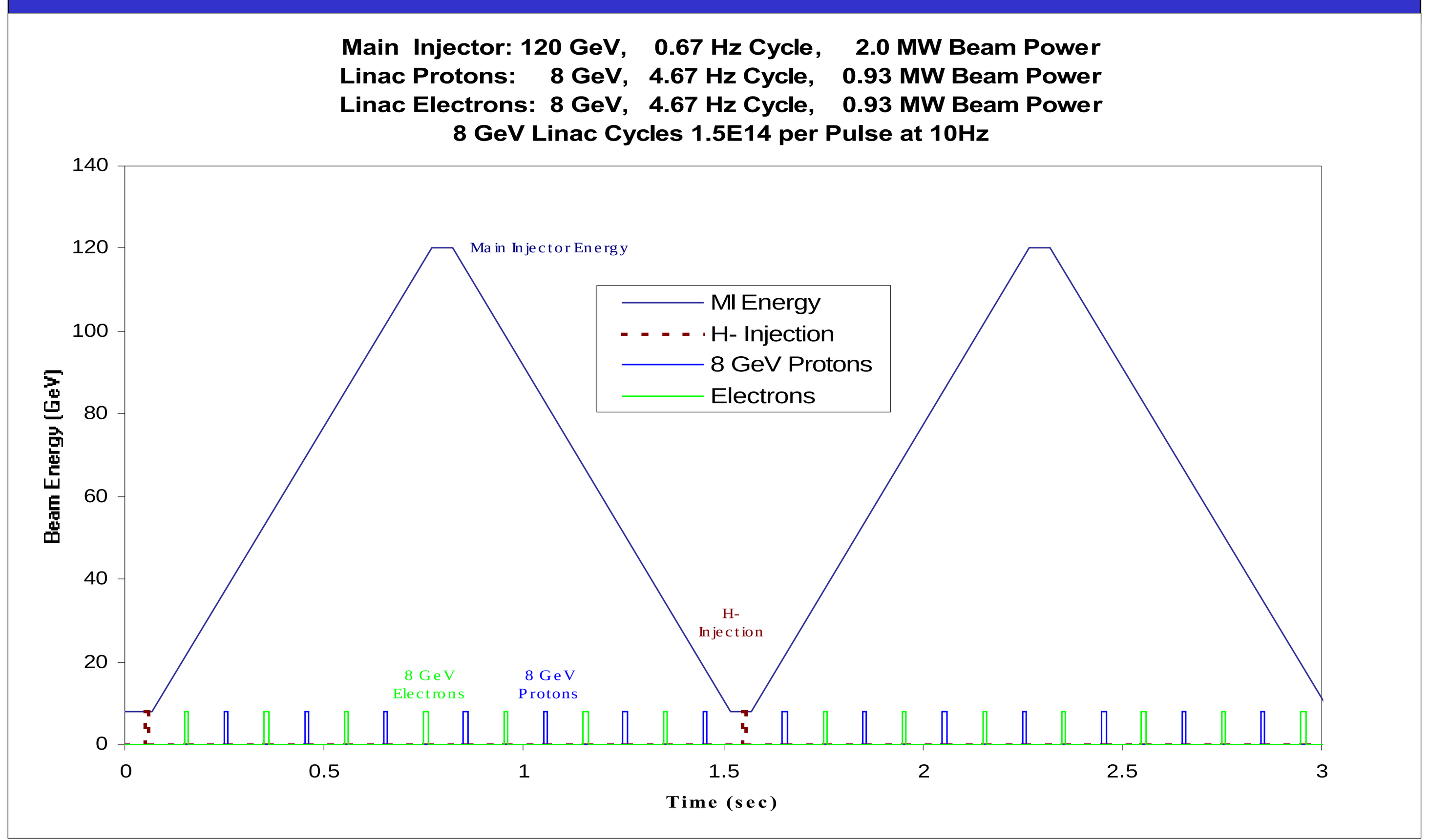
MI Beam Energy	GeV	120	
MI Beam Power	MW	2.0	
MI Cycle Time	sec	1.5	filling time = 1msec
MI Protons/cycle		1.5E+14	5x design
MI Protons/hr	P / hr	3.6E+17	
H-minus Injection	turns	90	SNS = 1060 turns
MI Beam Current	mA	2250	

G. W. Foster 14 Jan '02 4

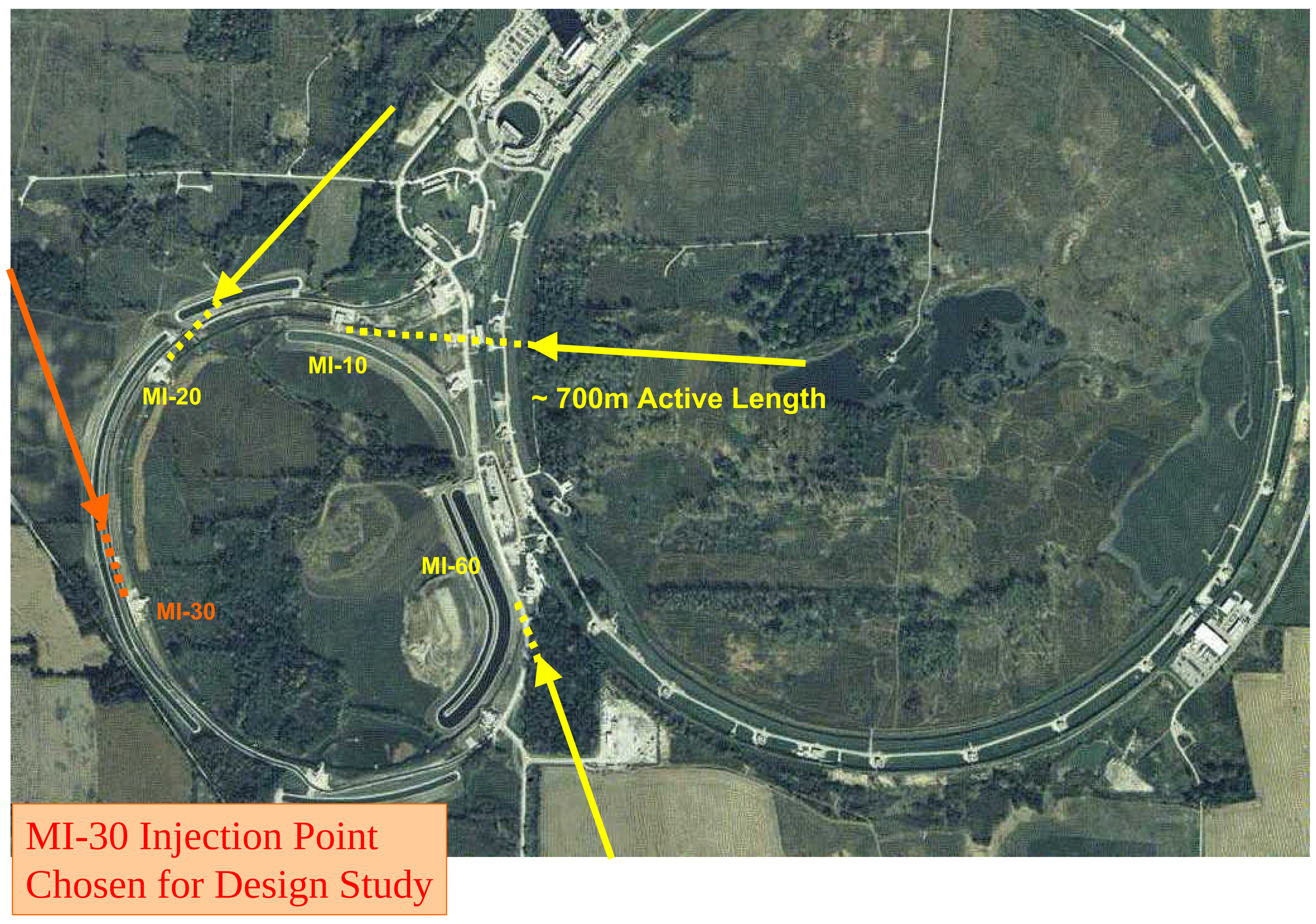
120 GeV Main Injector Cycle with 8 GeV Synchrotron



120 GeV Main Injector Cycle with 8 GeV Linac, e- and P

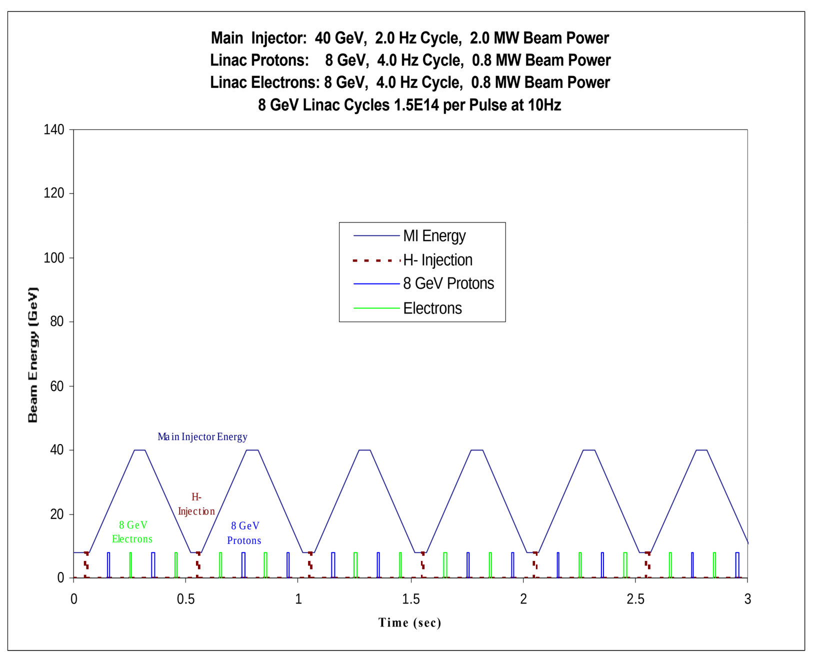


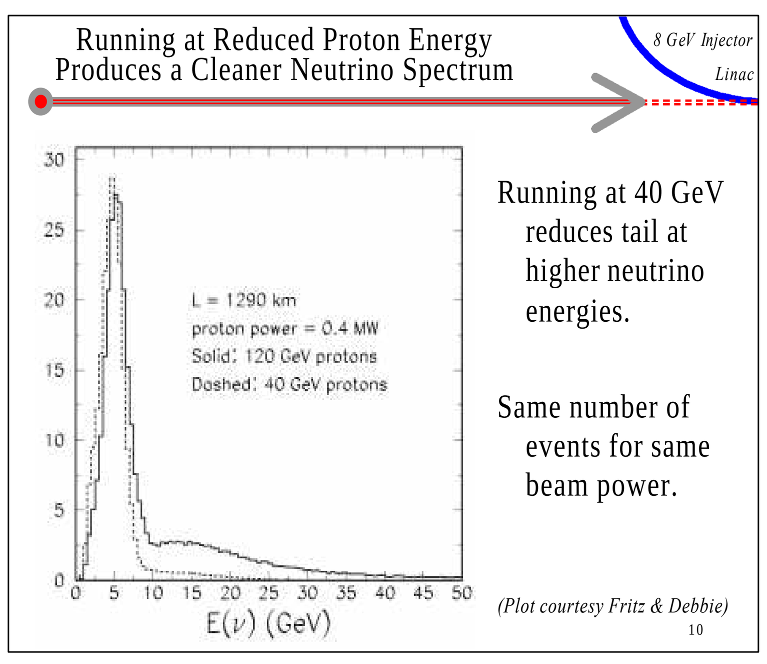
8 GeV Linac - Sitings Considered



MI-30 Injection Point
Chosen for Design Study

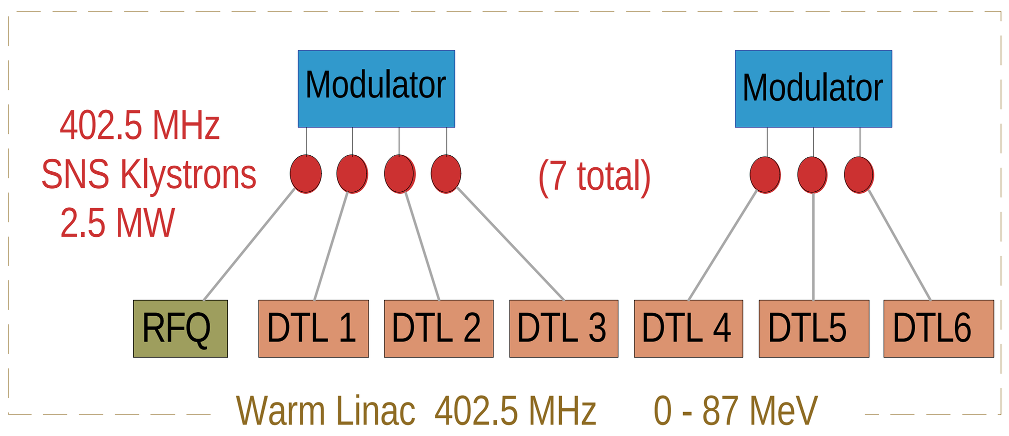
8 GeV Linac Allows Reduced MI Beam Energy without Compromising Beam Power





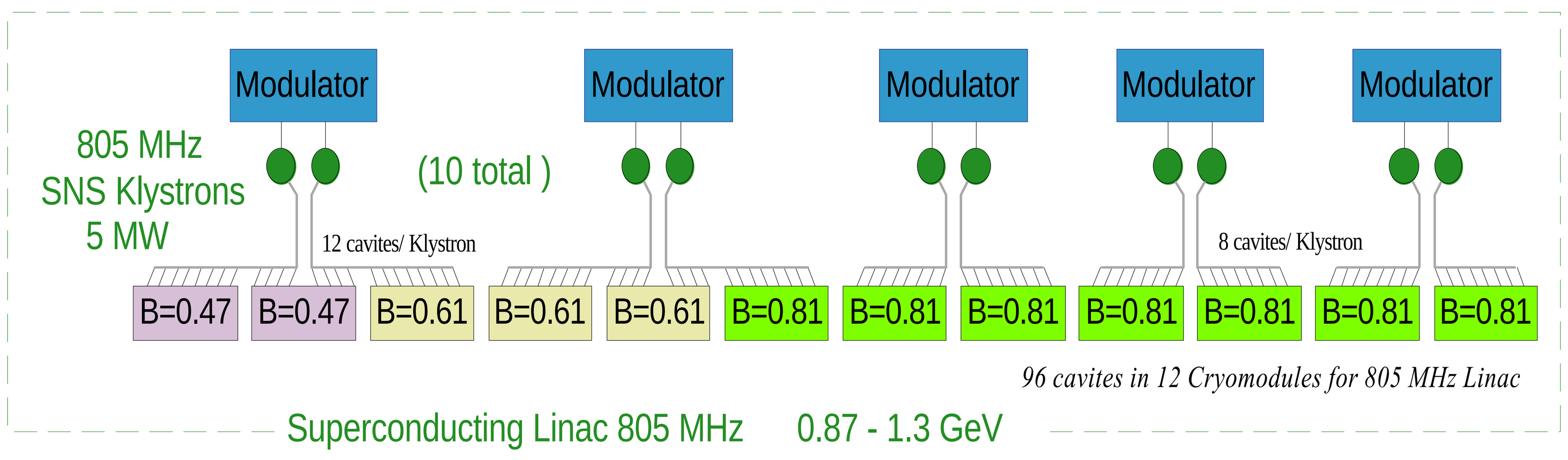
MI cycles to 40 GeV at 2Hz, retains 2 MW MI beam power

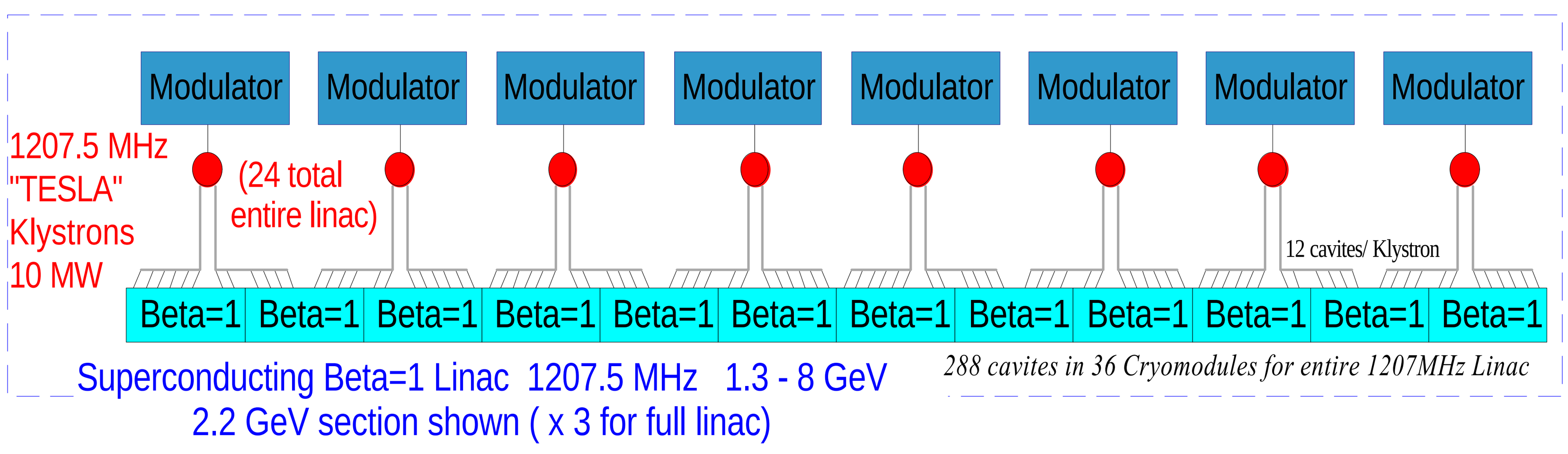
CRYOMODULES



8 GeV RF LAYOUT

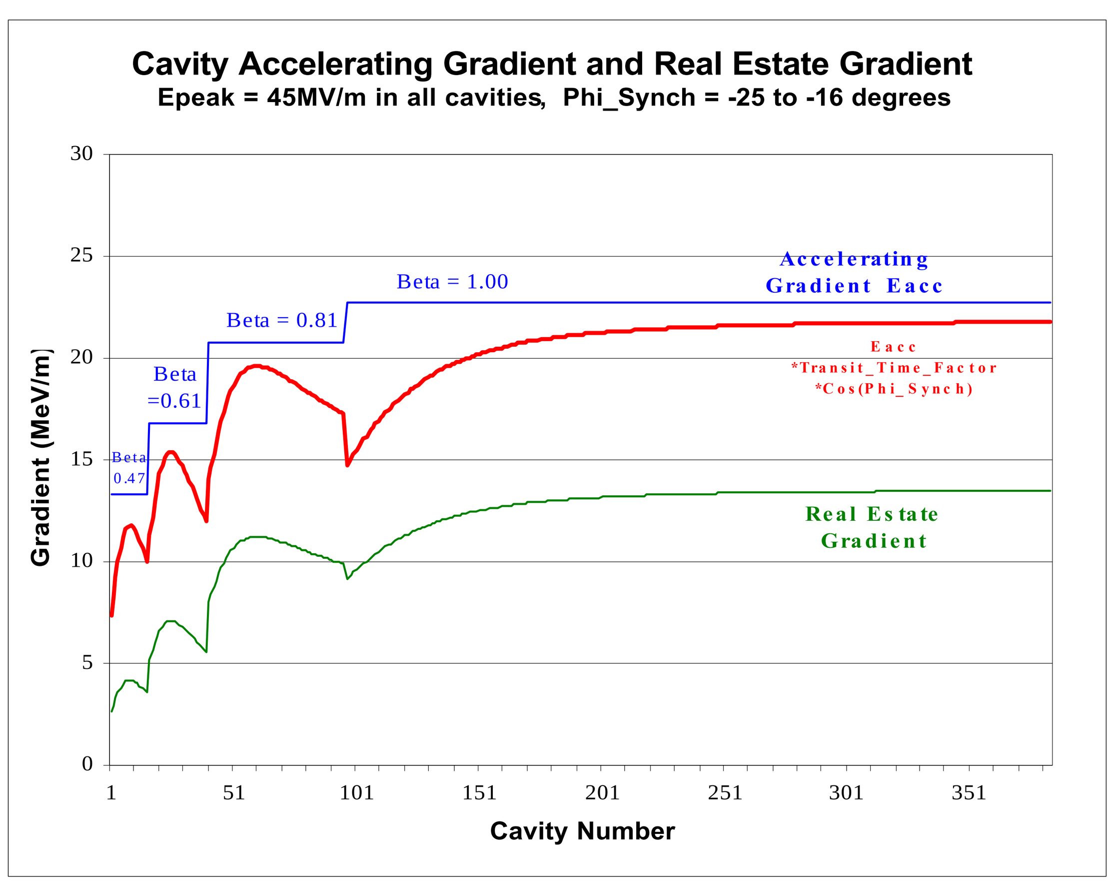
41 Klystrons (3 types)
31 Modulators 17 MW ea.
7 Warm Linac Loads
384 Superconducting Cavities
48 Cryomodules





Superconducting Cavity Gradients

8 GeV Injector Linac

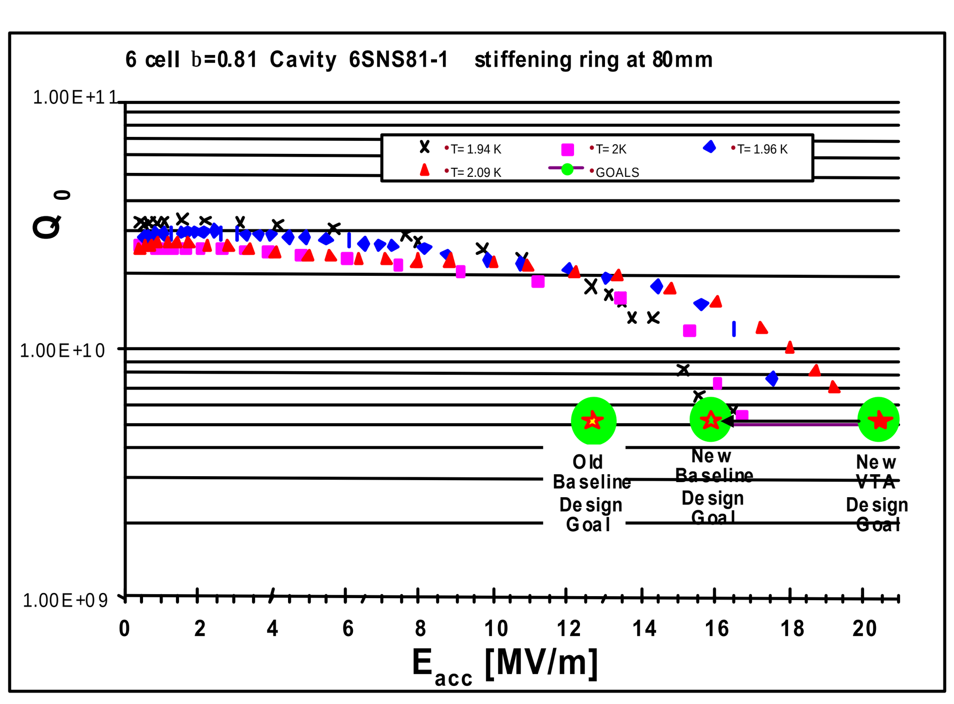


8 GeV design assumes *peak* field in cavities of 45 MV/m.

SNS: 37.5 MV/m
TESLA(500): 47 MV/m
TESLA(800): ~70 MV/m

SNS β = 0.81 Tests at TJNAF

8 GeV Injector Linac



[from N. Holtkamp Nov '01 SNS Review]

Eacc > 20 MV/m for protons is now reasonable design goal

CRYOMODULES

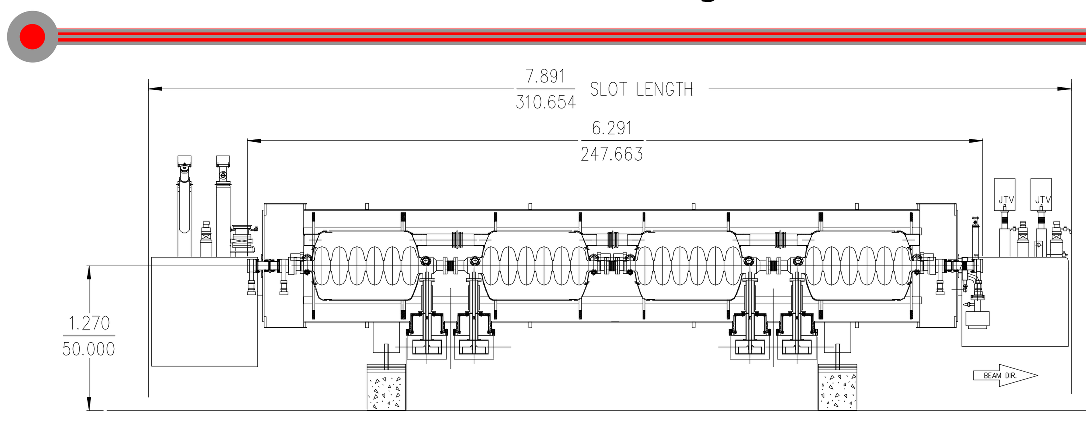
8 GeV Injector Linac

BIG Differences between SNS & TESLA

- Key Specification:
  - SNS Cryomodules can be swapped out in ~1 shift
  - TESLA cryomodule failure take 25 days to fix
    - comes from having 2.5km section of linac
  - 8 GeV LINAC: ~2 day repair time specified
    - possible because linac sector is much shorter ~300m

SNS/CEBAF Cryomodules

8 GeV Injector Linac

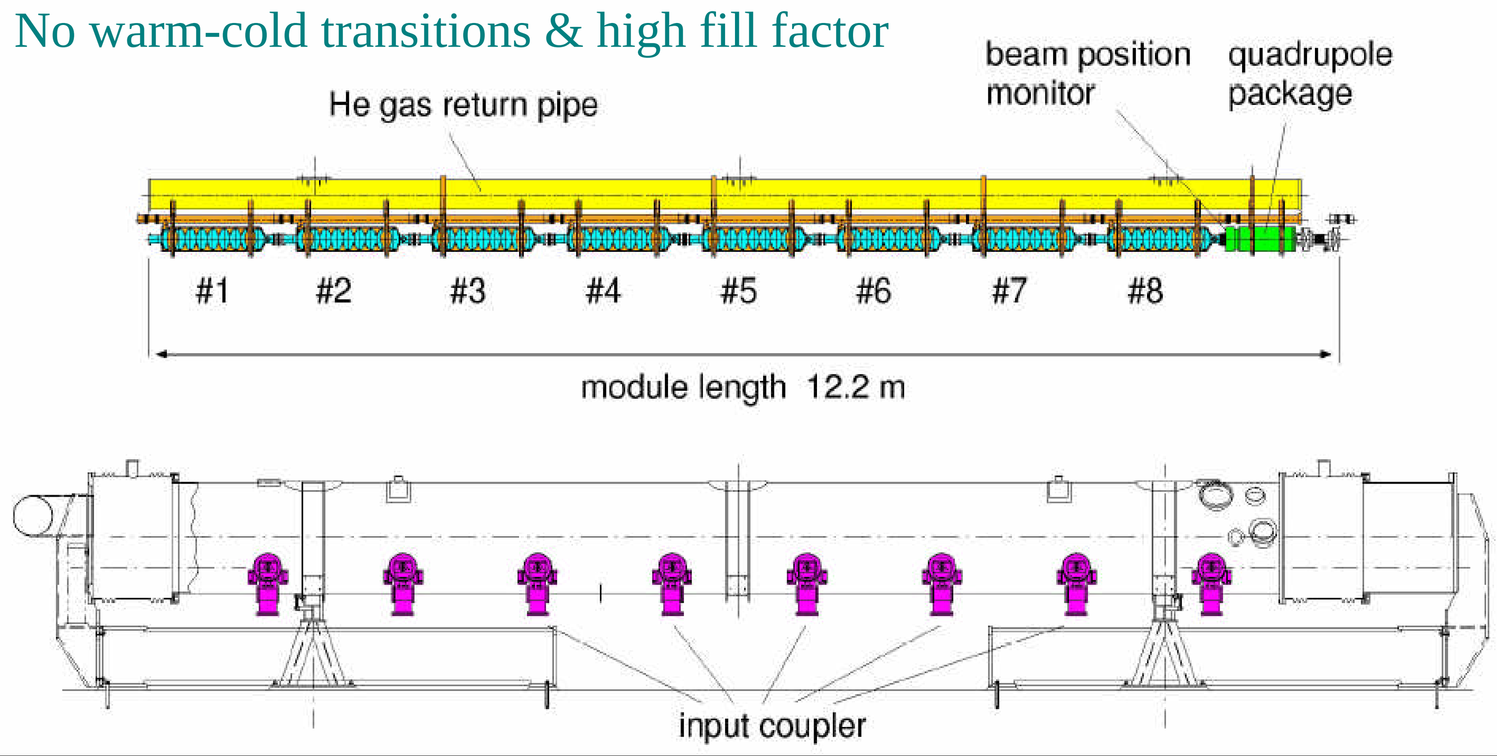


- Warm-to-cold beam pipe transition in each module
- 2K Coldbox, J-T & HTX in each Cryomodule
- Bayonet disconnects at each coldbox
- Only 2-4 cavities per cryomodule

Expensive Design forced by fast-swap requirement

TESLA Cryomodules

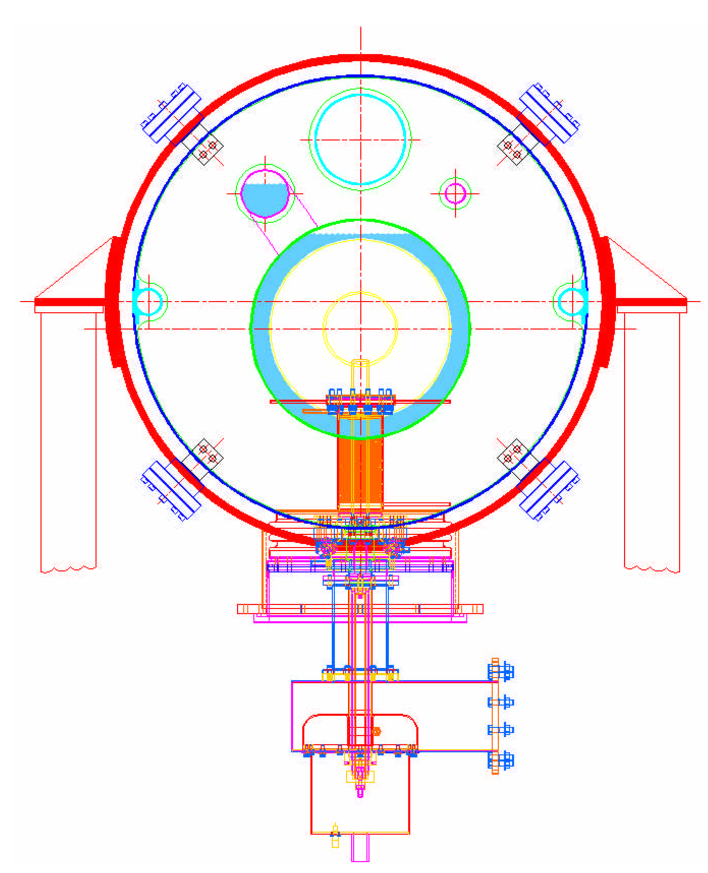
No warm-cold transitions & high fill factor



TESLA-Style Cryomodules for 8 GeV

(T. Nicol)

8 GeV Injector Linac



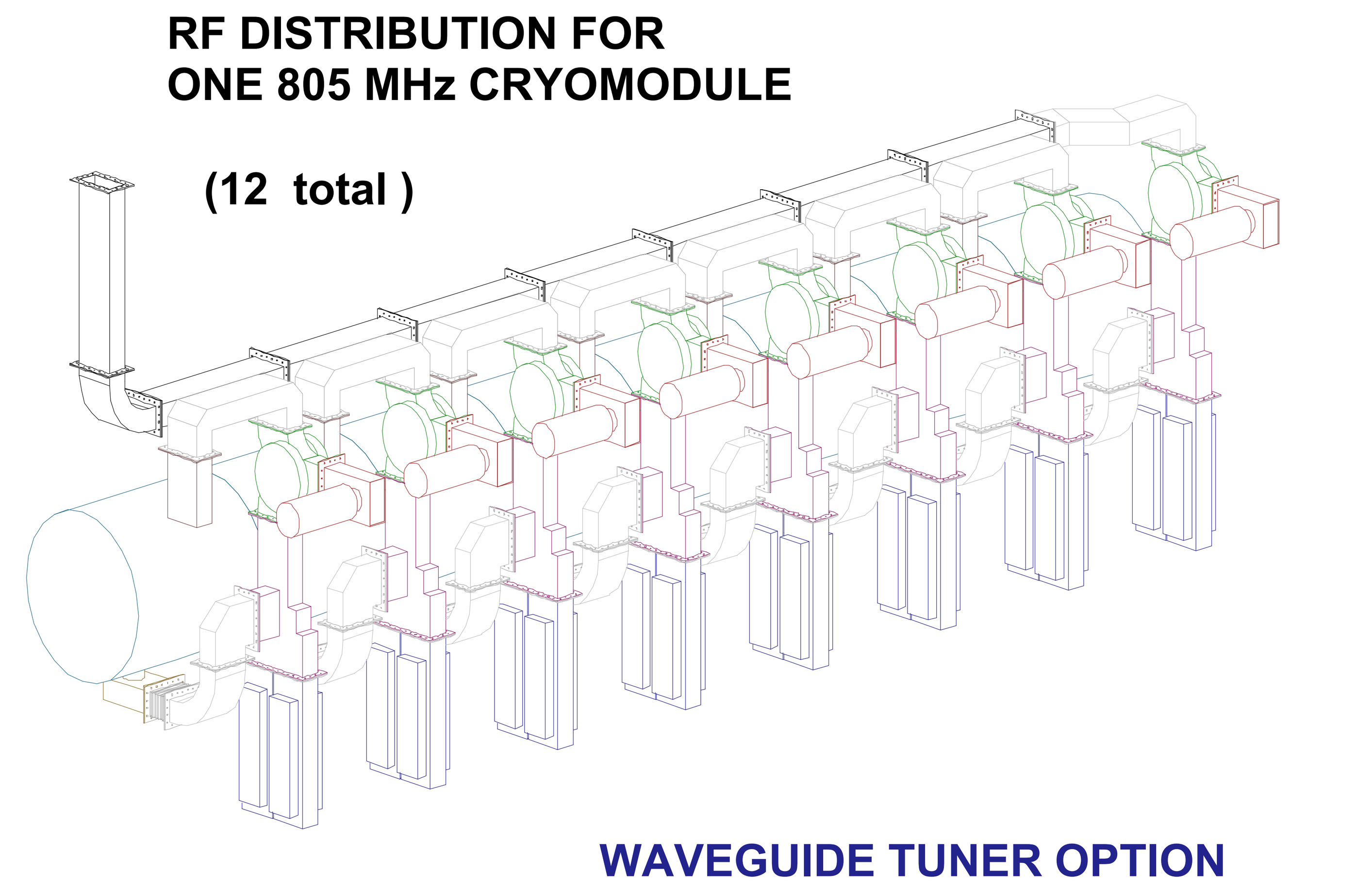
- Design conceptually similar to TESLA
- No warm-cold beam pipe transitions
- No need for large cold gas return pipe
- Cryostat can be *smaller* than TESLA (same as LHC)

TECHNICAL COMPONENTS

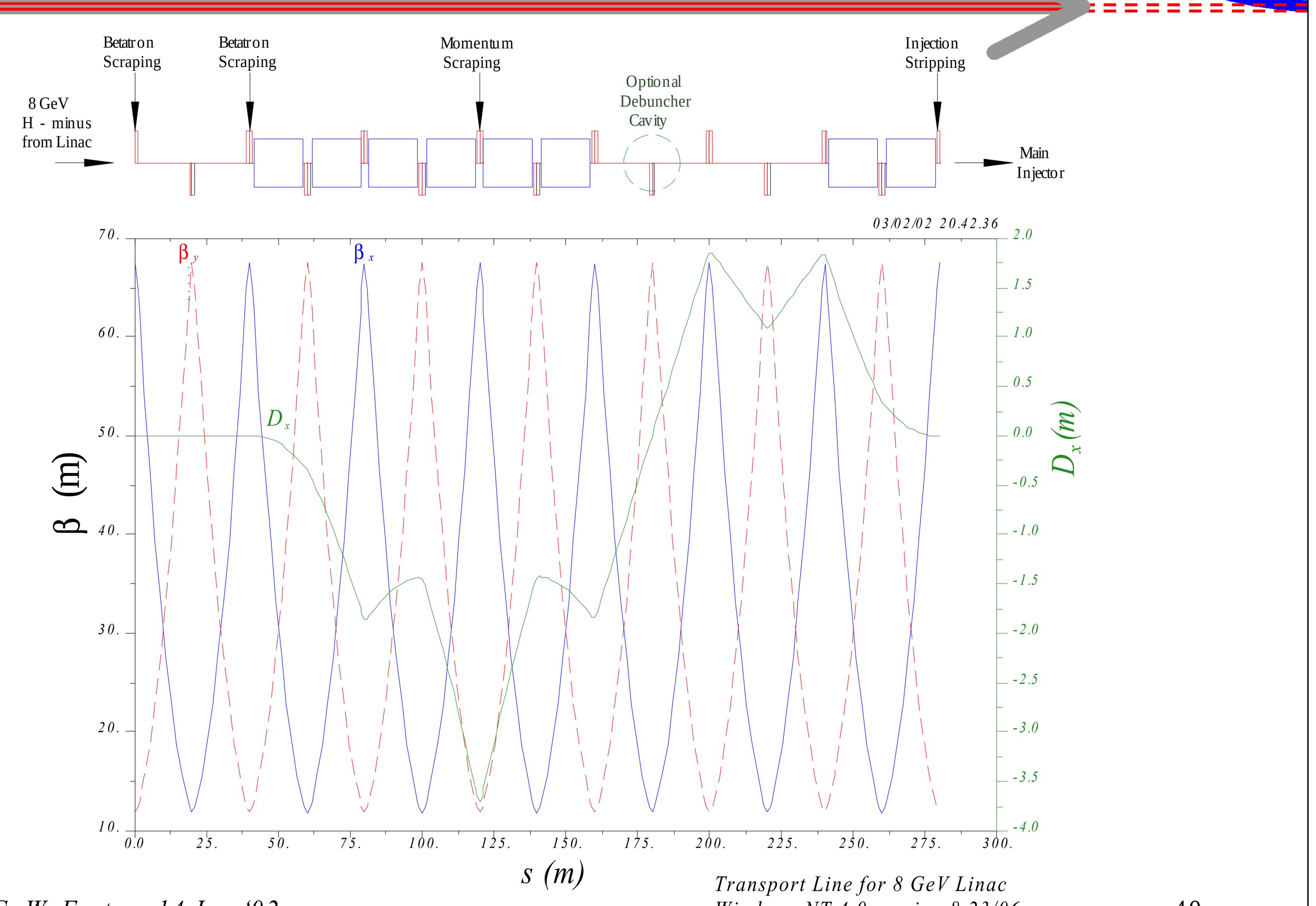
Modulators for Klystrons

- Biggest component in RF costs
- Pfeffer, Wolff, & Co. have been making TESLA spec modulators for years
- FNAL Bouncer design in service at TTF since 1994
- $1M ea.

805 MHz RF Distribution in Tunnel

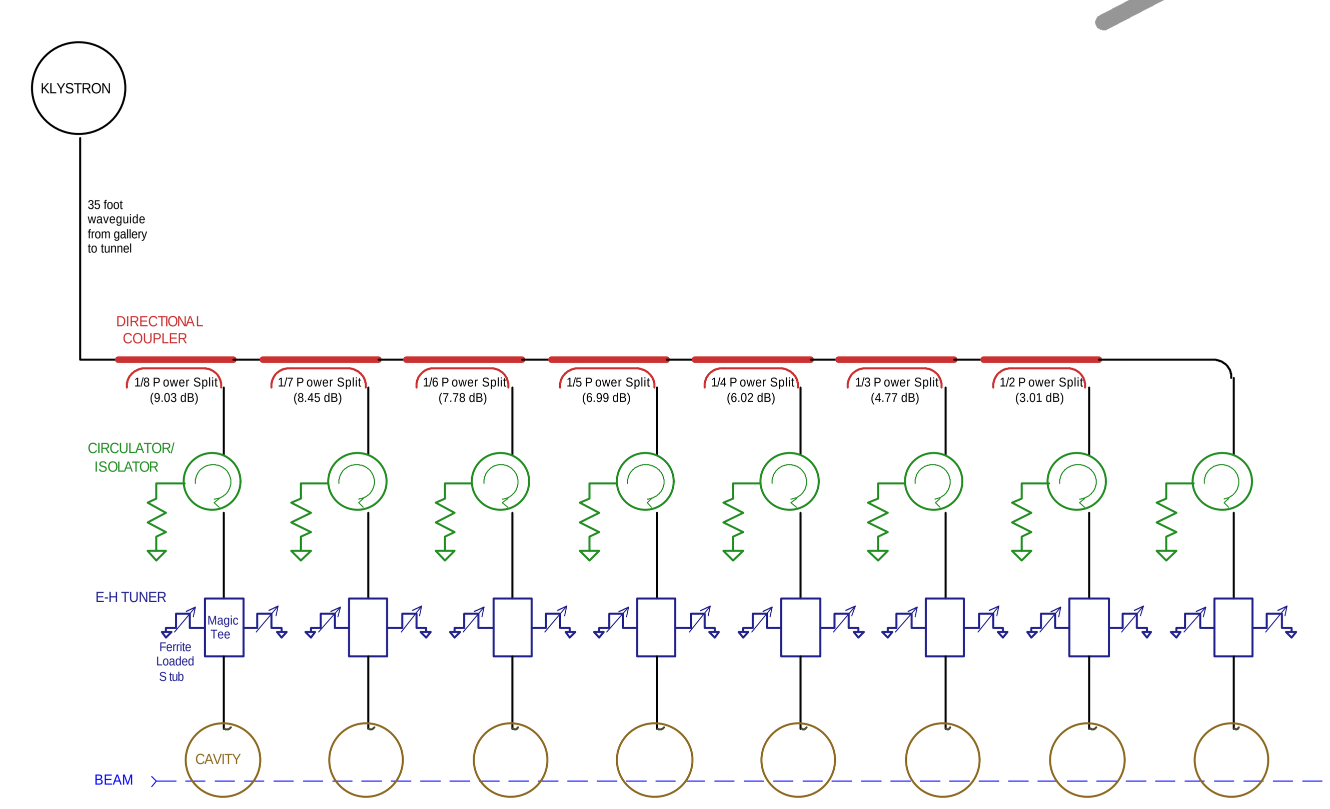


8 GeV Injection Line Optics with Betatron and Momentum Collimation



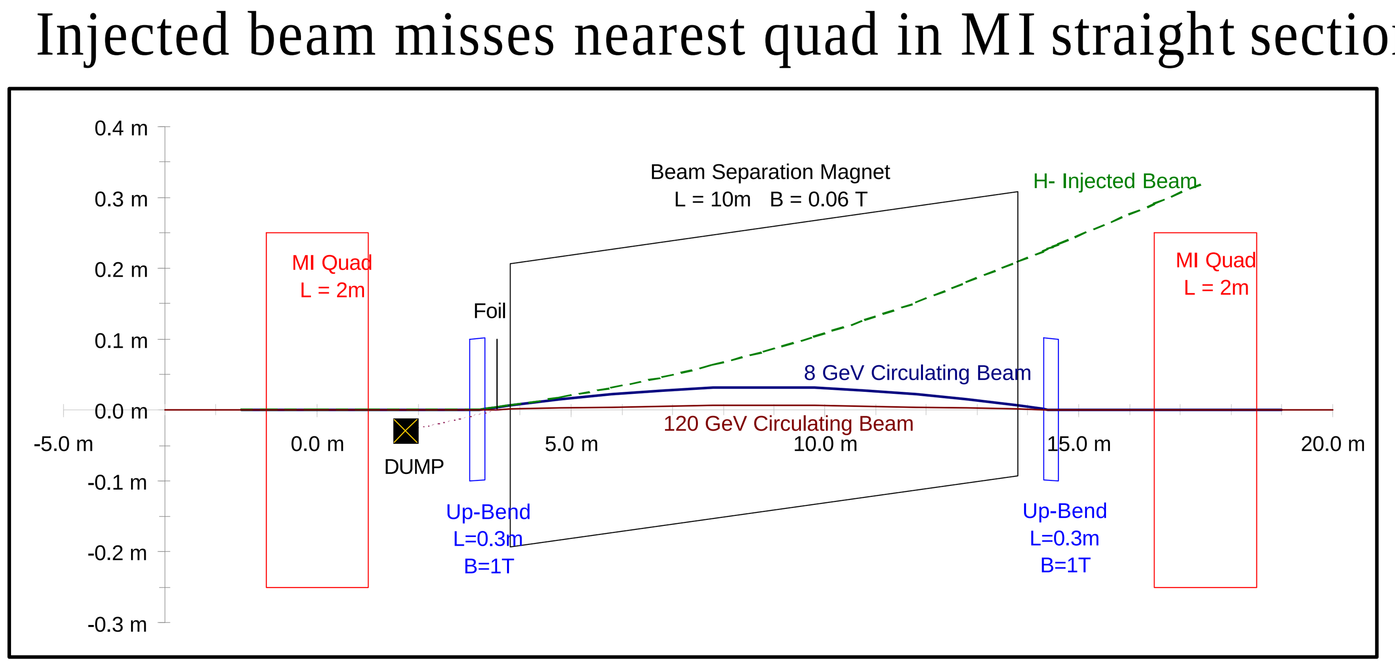
RF Fan-out for 8 GeV Linac

A. Moretti, D. Wildman

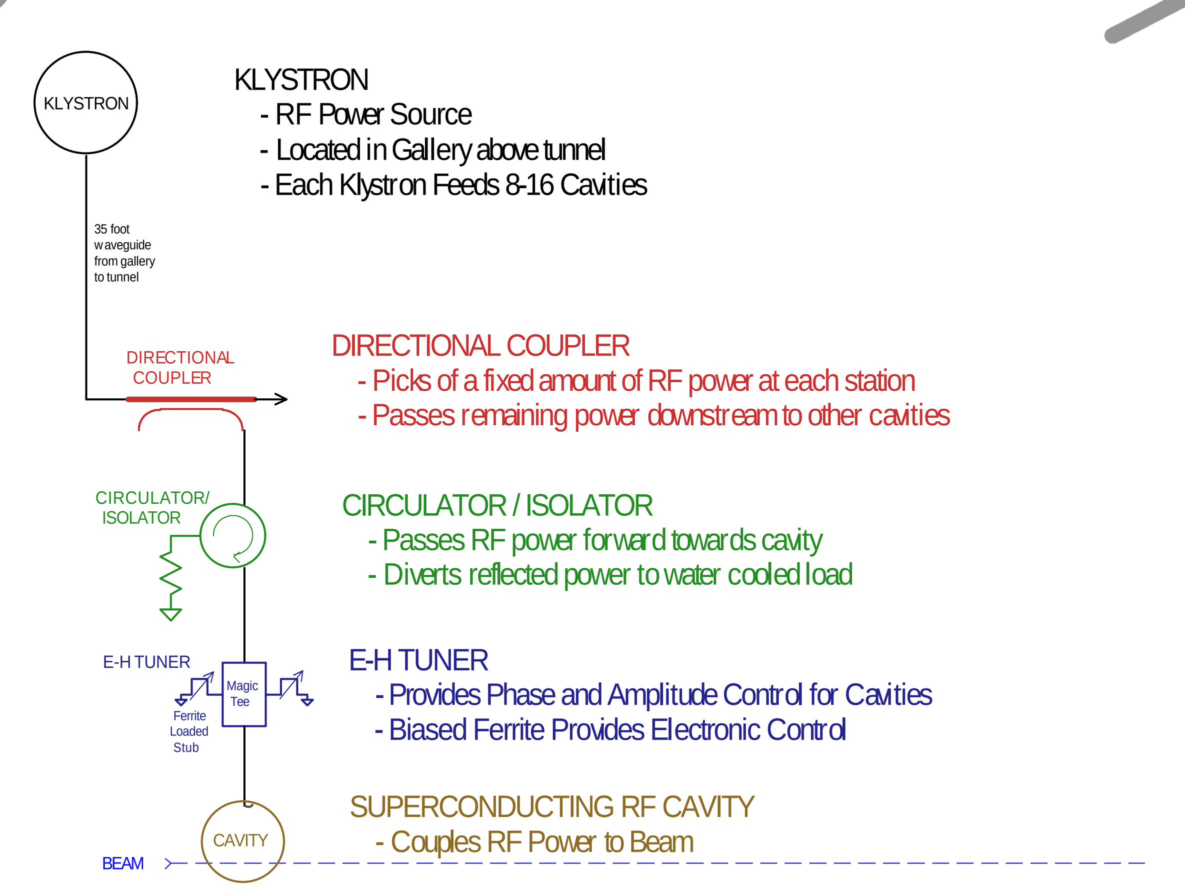


H- Injection Layout in MI

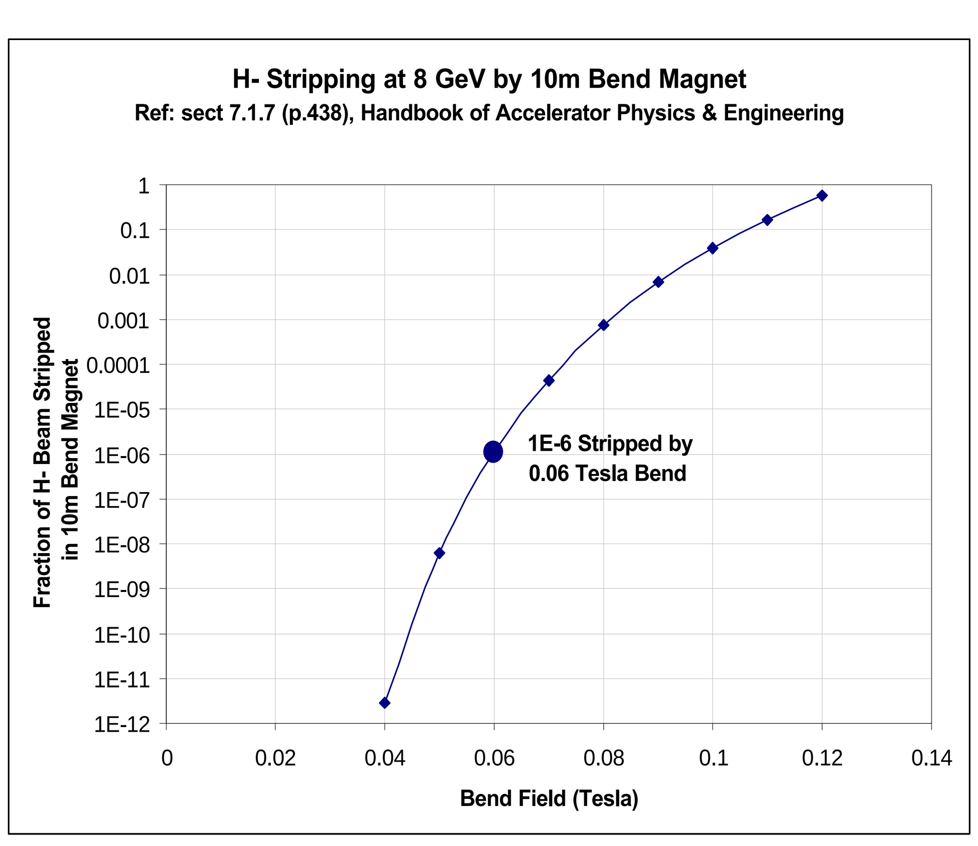
- Foil Stripping Injection at 8 GeV
- Slow orbit bump disappears as beam accelerates
  (fast, smaller orbit bump also required to escape foil)
- Injected beam misses nearest quad in MI straight section



RF Fanout at Each Cavity

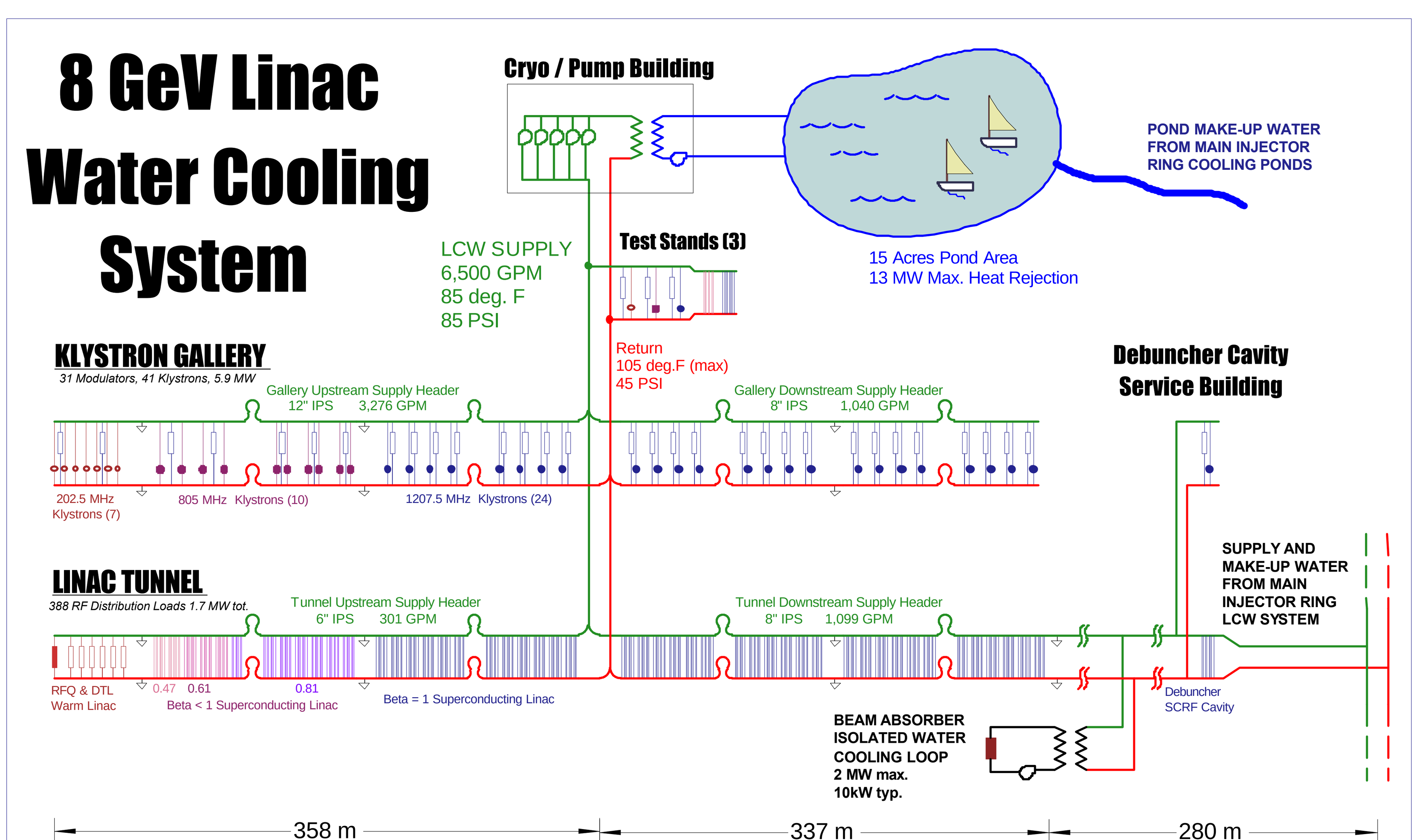


8 GeV H- Stripping in Magnets



- B= 0.06 Tesla strips only 1E-6 of Beam in 10m length
- 500m Bend Radius is OK
- Stripped Beam Power is <1 Watt

8 GeV Linac Water Cooling System



PROJECT COSTS?

AN ACTUAL COST BASIS

1) SNS Actual Cavity Costs

SNS Cavity Costs — *8 GeV Injector Linac*

- SNS recently ordered 109 cavities 1.2m long for: ($4M Niobium + $4.5M fab & process) ~ $80k per cavity
- The 8 GeV Linac needs 380 cavities 1.2m long (~ 400 including spares) ⇒ $32M for 8 GeV
- This assumes:
  - no quantity discount or rebate for existing tooling
  - that 1.2 GHz 9-cell cavities are the same price as 805 MHz 6-cell SNS cavities of same length

The cavity cost should not blow the budget

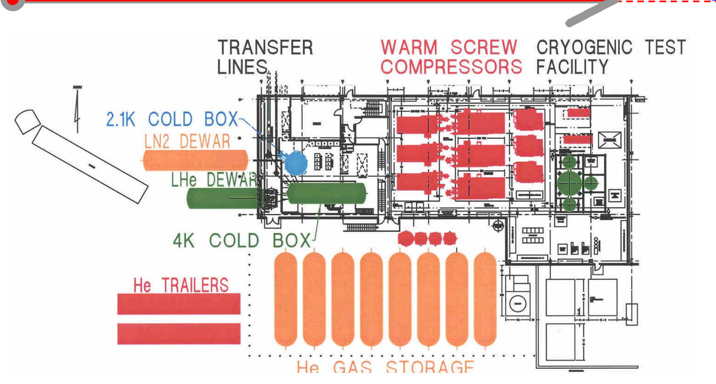
G. W. Foster 14 Jan '02 26

SNS Cavity Fabrication — *8 GeV Injector Linac*

G. W. Foster 14 Jan '02 24

2) SNS & LHC Actual Cryogenics Costs

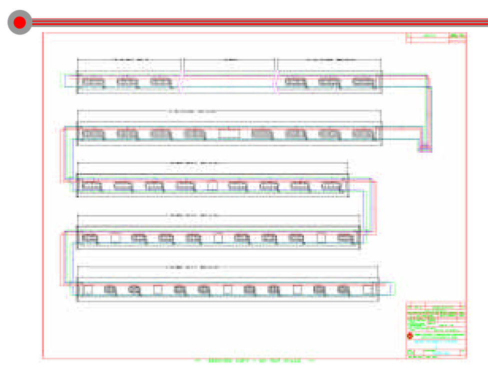
SNS CHL Facility — *8 GeV Injector Linac*



8 GeV Linac Cryoplant will be comparable ~$15M

G. W. Foster 14 Jan '02 29

CRYOGENICS & CRYO PLANT — *8 GeV Injector Linac*



- Arkadiy Klebaner is doing detailed analysis of 8 GeV linac cryogenic requirements & cost

G. W. Foster 14 Jan '02 37

3) FNAL Actual Costs for TTF Modulators

Modulators for Klystrons — *8 GeV Injector Linac*

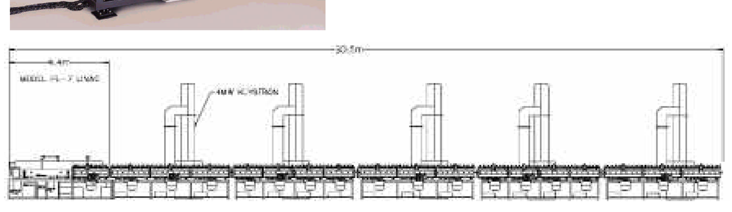
- Biggest component in RF costs
- Pfeffer, Wolff, & Co. have been making TESLA spec modulators for years
- FNAL Bouncer design in service at TTF since 1994
- $1M ea.

G. W. Foster 14 Jan '02 30

4) Commercial Quote for Front-End Linac

AccSys Source/RFQ/DTL — *8 GeV Injector Linac*

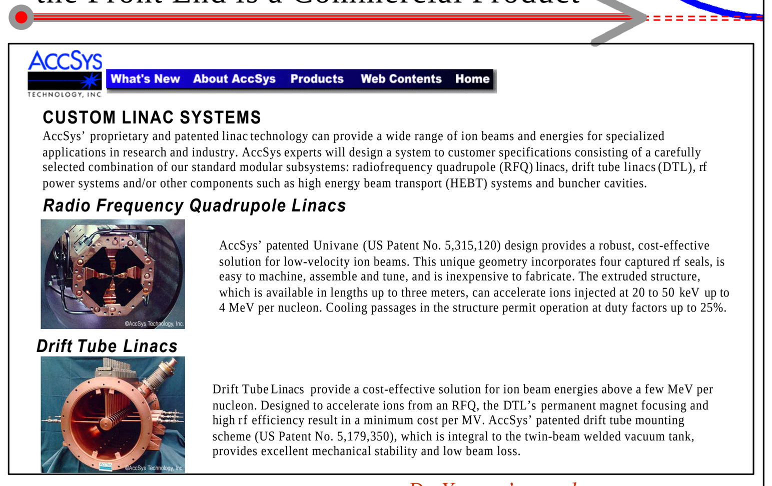
- AccSys PL-7 RFQ with one DTL tank



- Appears to have shorter length and lower price than cloning the SNS Linac, *for 10 Hz operation*

G. W. Foster 14 Jan '02 *D. Young's work...* 22

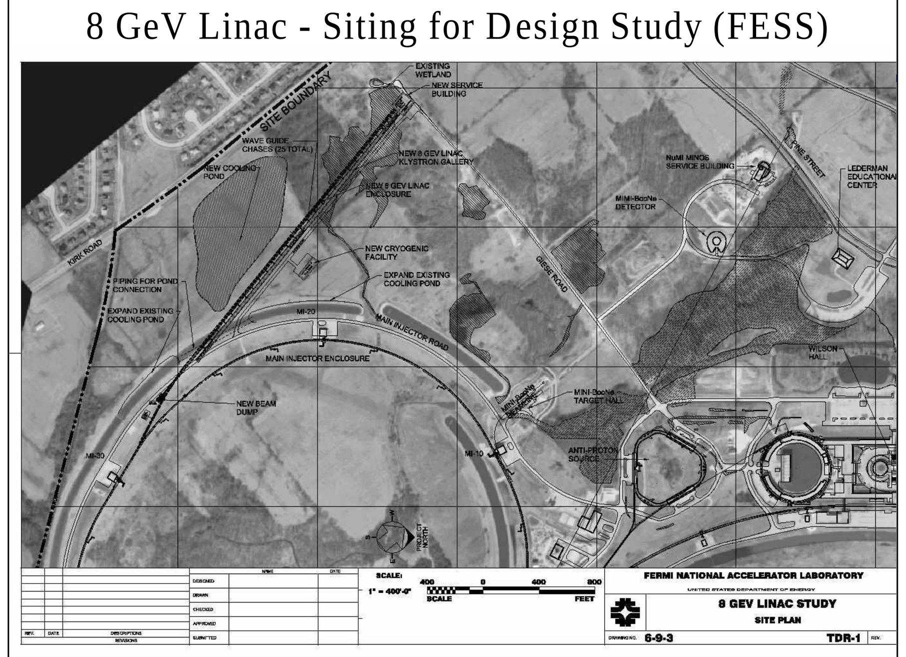
At Reduced RF Duty Cycle of ~1%, the Front End is a Commercial Product — *8 GeV Injector Linac*



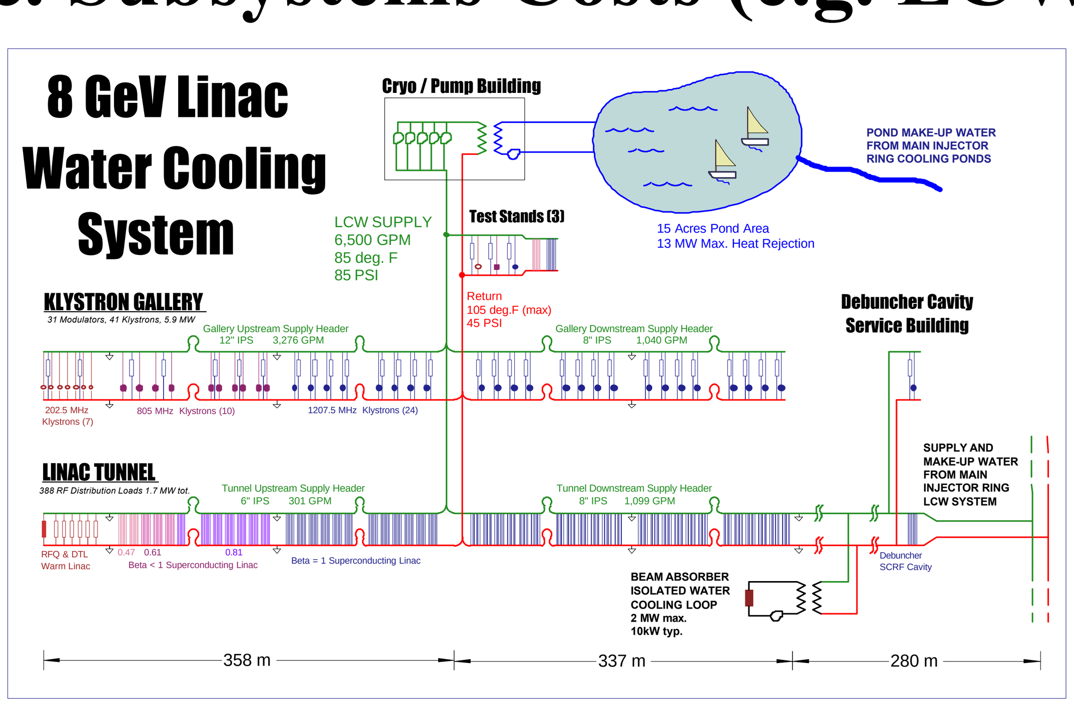
G. W. Foster 14 Jan '02 *D. Young's work...* 19

5) Civil Costs from FNAL Main Injector

8 GeV Linac - Siting for Design Study (FESS)



6) Misc. Subsystems Costs (e.g. LCW)



Very Rough Cost Estimates — *8 GeV Injector Linac*

1) Scaled from TESLA costs
2) Scaled from SNS actual costs
3) First stab at bottom-up cost est.
   - use SNS actual costs where reasonable
   - independent, bottom-up cost estimates elsewhere
   - *Not yet completed but this is the way to go.*

G. W. Foster 14 Jan '02 10

Rough Cost, Scaled from TESLA — *8 GeV Injector Linac*

• TESLA Project Cost (European)	$3B
• subtract damping rings, IR, Injector	$2.5B
• US Cost Basis (x2) for bare linac	$5B
• Scale to 7 GeV (7/500) = 1.4%	$70M
• TESLA Quantity Discount $(7/500)^{-0.074}$ =1.37	$100M
• Include Fixed Project Cost ($50M??)	**$150M**

G. W. Foster 14 Jan '02 10

Rough Cost, Scaled from SNS — *8 GeV Injector Linac*

• SNS Project Cost	$1300M
• SC Linac Cost (approx, incl. civil)	$250M
• Scale SCRF by energy (7.6/0.8)	x10
	$2.5 B

There are many good technical reasons why the TESLA linac should be cheaper. But how much?

We need detailed breakdowns to understand the apparent disconnect between TESLA and SNS cost estimates.

G. W. Foster 14 Jan '02 10

CONCLUSIONS — *8 GeV Injector Linac*

- An 8 GeV Injector Linac will be a useful component at FNAL no matter what future machine is built.
- There are no technical difficulties, just further optimizations. Can copy existing designs.
- It should make FNAL complex simpler to run.
- The cost could be similar to the Main Injector and Proton Driver.

G. W. Foster 14 Jan '02 77